DOCUMENT RESUME

ED 364 564 TM 020 717

AUTHOR	Shute, Valerie J.; Gawlick-Grendell, Lisa A.
TITLE	If Practice Makes Perfect, What Does Less Practice Make? Interim Technical Paper for Period March 1991-March 1992.
INSTITUTION	OAO Corp., San Antonio, TX.
SPONS AGENCY	Armstrong Lab, Brooks AFB, TX. Human Resources Directorate.
REPORT NO	AL-TP-1992-0017
PUB DATE	Jun 92
CONTRACT	PE-61102F
NOTE	16p.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Adults; *Computer Assisted Instruction; Educational Environment; Flight Training; Higher Education; Job Training; *Learning; Military Training; Outcomes of Education; Performance; *Problem Solving; *Transfer of Training; Vocational Education
IDENTIFIERS	Computer Tutors; *Intelligent Tutoring Systems; *Practice

ABSTRACT

This research examines the subject of practice and transfer effects using an intelligent tutoring system (ITS) teaching novel knowledge and skills (i.e., flight engineering). Previous research has shown that when more time is spent exercising new cognitive skills, performance is improved and the cognitive load is reduced. Other research has demonstrated that when the number or variety of example problems is small, learning tends to be rapid, but transfer tends to be weak. The purpose of this research was to test these ideas in a controlled setting using an ITS that was manipulated to yield 2 contrasting learning environments: "extended" (12 problems per problem set), and "constrained" (3 problems per problem set). Subjects were 356 male and female adult high school graduates without any experience in flight engineering. The environments differed only in the number of practice problems requiring solution in the various problem sets. Results show that while subjects in the constrained environment completed the curriculum significantly faster than did subjects in the extended version, there were no differences between conditions on any of the outcome measures. But when the data were examined across problem sets, latency and error-type differences between the two groups were found. Three figures and one table present study findings. (Contains 8 references.) (Author/SLD)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 364 564

AL-TP-1992-0017

IF PRACTICE MAKES PERFECT, WHAT DOES LESS PRACTICE MAKE?

Valerie J. Shute

HUMAN RESOURCES DIRECTORATE
MANPOWER AND PERSONNEL RESEARCH DIVISION
Brooks Air Force Base, TX 78235-5000

Lisa A. Gawlick-Grendell

OAO Corporation
1222 N. Main Avenue
San Antonio, TX 78212

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
☒ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

June 1992

Interim Technical Paper for Period March 1991 – March 1992

Approved for public release; distribution is unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

ARMSTRONG LABORATORY

TM 026717

BEST COPY AVAILABLE

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

VALERIE J. SHUTE
Project Scientist

WILLIAM E. ALLEY, Technical Director
Manpower and Personnel Research Division

ROGER W. ALFORD, Lt Col, USAF
Chief, Manpower and Personnel Research Division

BEST COPY AVAILABLE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1992	Interim – March 1991 – March 1992

4. TITLE AND SUBTITLE
If Practice Makes Perfect, What Does Less Practice Make?

5. FUNDING NUMBERS
PE – 61102F
PR – 2313
TA – T1
WU – 44

6. AUTHOR(S)
Valerie J. Shute
Lisa A. Gawlick-Grendell

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Manpower and Personnel Research Division
Brooks Air Force Base, TX 78235-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
AL-TP-1992-0017

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This research examines the subject of practice and transfer effects using an intelligent tutoring system (ITS) teaching novel knowledge and skills (i.e., flight engineering). Previous research has shown that when more time is spent exercising new cognitive skills, performance is improved and the cognitive load is reduced (e.g., Ackerman, 1988; Anderson, 1987; Schneider & Shiffrin, 1977). Other research has demonstrated that when the number (or variety) of example problems is small, learning tends to be rapid, but transfer tends to be weak (e.g., Carlson & Yaure, 1990; Gick & Holyoak, 1987). The purpose of this paper was to test these ideas in a controlled setting using an ITS that was manipulated to yield two contrasting learning environments: "extended" (12 problems per problem set) and "constrained" (3 problems per problem set). These environments differed only in the number of practice problems requiring solution in the various problem sets. Results showed that while subjects in the constrained environment completed the curriculum significantly faster than subjects in the extended version, there were no differences between conditions on any of the outcome measures. But when the data were examined across problem sets, latency and error-type differences between the two groups were found.

14. SUBJECT TERMS
Intelligent tutoring system
Learning environment
Practice effects
Skill acquisition
Transfer effects

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
METHOD	2
Subjects	2
Flight Engineering Tutor	2
Learning Outcome Measures	4
Error Types	6
Procedure	6
RESULTS	6
DISCUSSION	9
REFERENCES	10

List of Figures

Fig. No.		
1	Examples of Problem Set for Determining Maximum Allowable Crosswind Given Gross Weight and RCR	4
2	Seven-Step Solution for Solving Headwind and Crosswind Problems from the Wind Components Chart	5
3	Latency and Error Data Across Problem Sets	8

List of Tables

Tab. No.		
1	Posttest Scores Separated by Learning Environment	7

PREFACE

We would like to sincerely thank the many people who assisted in the conduct of this research. Pat Kyllonen and Bill Alley provided us with valuable comments and suggestions on this article.

The research reported in this paper was conducted as part of the Armstrong Laboratory, Human Resources Directorate--Learning Abilities Measurement Program (LAMP). This study represents basic research funded by the Air Force Office of Scientific Research. The opinions expressed in this article are those of the authors and do not necessarily reflect those of the U.S. Air Force.

Correspondence concerning this paper should be addressed to Valerie J. Shute, Armstrong Laboratory, Human Resources Directorate, Individual Attributes Branch, Brooks Air Force Base, Texas 78235-5000.

IF PRACTICE MAKES PERFECT, WHAT DOES LESS PRACTICE MAKE?

SUMMARY

"Practice makes perfect"--more time spent exercising new cognitive skills results in improved performance and reduced cognitive load (e.g., Ackerman, 1988; Anderson, 1987; Schneider & Shiffrin, 1977). In addition, when the number (or variety) of example problems is small, learning tends to be rapid, but transfer tends to be weak (e.g., Carlson & Yaure, 1990; Gick & Holyoak, 1987). This paper examined these issues in a controlled setting using an intelligent tutoring system teaching novel knowledge and skills (i.e., flight engineering). We manipulated the tutor to yield two contrasting learning environments: "extended" (12 problems per problem set) and "constrained" (3 problems per problem set). These environments differed only in the number of practice problems requiring solution in the various problem sets. While subjects in the shorter version were expected to complete the curriculum faster, we wanted to examine practice effects on learning outcome (transfer) and skill acquisition (error and latency analyses). Results showed that while subjects in the constrained environment completed the curriculum significantly faster than subjects in the extended version, there were *no differences* on any of the outcome tests. Moreover, when the data were examined across problem sets, latency and error-type differences between the two groups were found.

INTRODUCTION

An enduring expression that has a lot of empirical support in cognitive psychology is that "practice makes perfect" (e.g., Ackerman, 1988; Anderson, 1987; Fisk, in press; Schneider & Shiffrin, 1977; Woltz, 1988). Increasing the time allocated to exercising a new cognitive skill typically results in improved performance and a reduced cognitive load. A related finding is that when the number (or variety) of example problems is small, learning tends to be rapid, but transfer tends to be weak (e.g., Carlson & Yaure, 1990; Gick & Holyoak, 1987). Thus, more and varied practice problems lead to more effective skill acquisition. But how many practice problems are sufficient? Alternatively, how <u>few</u> practice problems can be provided that will yield comparable learning outcomes to richer practice environments?

The purpose of this paper is to investigate the effects of practice on learning outcome. Other questions address the relationship between practice effects and the learning process. In particular, what are the effects of practice on learning curves and errors made during skill acquisition? For example, do subjects tend to compensate for fewer practice problems by adjusting (increasing) their time spent learning each problem? Is there an effect of practice on the number or nature of errors made during the learning process?

We will present results from a large-scale experiment that was designed to test practice effects from a systematically altered tutoring system teaching flight engineering skills. We manipulated the tutor to yield two contrasting learning environments, differing only in the number of problems the learner needed to solve in each of nine different problem sets. The version with many problems was called "extended" (12 problems per problem set). The version with fewer problems to solve was called "constrained" (3 problems per set). A fixed ratio of 4:1 existed between the two tutor versions.

The simple hypotheses were that (a) subjects assigned to the *constrained* environment should take less time to complete the tutor because there were considerably fewer problems for them to solve. However, (b) these same subjects were not expected to perform as well on the posttests compared with subjects learning from the extended environment who would have received considerably more practice solving tutor-related problems. In addition, we expected that (c) subjects would tend to adjust their learning times per problem where those in the short version would, over time, take longer to solve each of their three problems (per problem set) compared to subjects in the longer version. This adjustment was expected to occur gradually, as learners realized they had fewer problems and thus invested more time per problem. Finally, we hypothesized that (d) subjects in the constrained version would manifest more conceptual (rather than computational) errors during learning given their sparse practice environment.

METHOD

Subjects

The subjects in this study consisted of 356 males and females participating in a seven-day study on the acquisition of flight engineering knowledge and skills from an intelligent tutoring system. The gender distribution in the sample was approximately 75 percent males and 25 percent females. All subjects were high school graduates with a mean age of 22 years. Subjects were obtained from a local temporary employment agency and were paid for their participation, consisting of forty-five hours of testing and learning. None of the subjects had any prior experience or training as flight engineers or pilots.

Flight Engineering Tutor

The tutor was originally developed at the University of Pittsburgh (Lesgold, Bunzo, & Eastman, 1989) and then modified at the Armstrong Laboratory to fit experimental objectives. The tutor was designed to teach knowledge and skills associated with a flight engineer's job. Job components include collecting and analyzing information about a pending flight and deciding whether various factors (e.g., weather and runway conditions, type of aircraft) indicate a safe flight. There were two parts to the curriculum: graph reading, and computing values for inclusion in the TOLD (Take Off and Landing Data) sheet. The focus of

this paper is on performance within the second, more substantive, part of the tutor dealing with completing the TOLD worksheet.

The TOLD worksheet part of the curriculum consisted of nine problem sets and involved applying the graph reading skills taught earlier to fill in the TOLD worksheet. The on-line worksheet was designed to match the actual forms used by flight engineers. Information must be assembled and entered into the proper cells. Some information was given to the learners (e.g., gross weight of the aircraft, wind direction and velocity, the length, heading, and conditions of the runway, obstacles in the flight path). Other information had to be derived from complex graphs and then entered into the correct cells of the worksheet. For instance, the wind-components chart is used to compute the headwind, tailwind, or crosswind components, and consists of two superimposed charts: polar and Cartesian coordinates. On-line tools were available to assist the learner in making the necessary computations. Some of the tools that could be used with the wind-components chart included: draw vertical or horizontal lines, add a radius or vector, erase lines, redisplay graph, and so forth. A "Help" window allowed the learner to read related information about the topic under study. Learning was self-paced.

The first (and easiest) set of problems (sets 1, 2, and 3) involved computing the *maximum allowable crosswind* given the gross weight of the aircraft and the runway condition reading (RCR). These problem sets became progressively more difficult. Prior to the problem-solving phase in each problem set, concepts or procedures related to the problem set were discussed and illustrated by the tutor in detail. For example, the tutor explicitly demonstrated how to figure out the *maximum allowable crosswind* before presenting any problems (see Figure 1). First, the relevant chart was displayed on the computer screen. Then the computer drew a vertical line up from the x-axis (corresponding to the given gross weight of the aircraft) to intersect the appropriate RCR. A second line was displayed moving horizontally across from the RCR curve to the y-axis. The intersection at the y-axis yielded the crosswind value. Text always accompanied the visual (dynamic) displays, for example, "*The MAXIMUM ALLOWABLE CROSSWIND FOR TAKEOFF chart is shown below. To use the chart, values from two variables are needed: (1) Gross weight of the aircraft and (2) Runway condition reading (RCR). RCR is a measure of the tire-to-runway coefficient of friction...*"

The second cluster of problem sets (4, 5, and 6) involved computing the headwind, crosswind, and tailwind components, respectively. Here, subjects had to apply rules learned earlier about what constituted various wind types. For example, the headwind rule was: If the relative wind direction is less than 90 degrees (i.e., 0 to 89), or greater than 270 degrees (i.e., 271 to 360), then it is a "headwind." Figure 2 illustrates a "headwind" problem. Given the wind direction, runway heading, wind velocity, and gust (see Figure 2), the "relative wind direction" was determined from subtracting the wind direction from the runway heading (smaller value from the larger). Another rule is that gust values are not added to headwinds, but are added to crosswinds and tailwinds. A seven-step procedure is shown in Figure 2 computing the headwind and crosswind components.

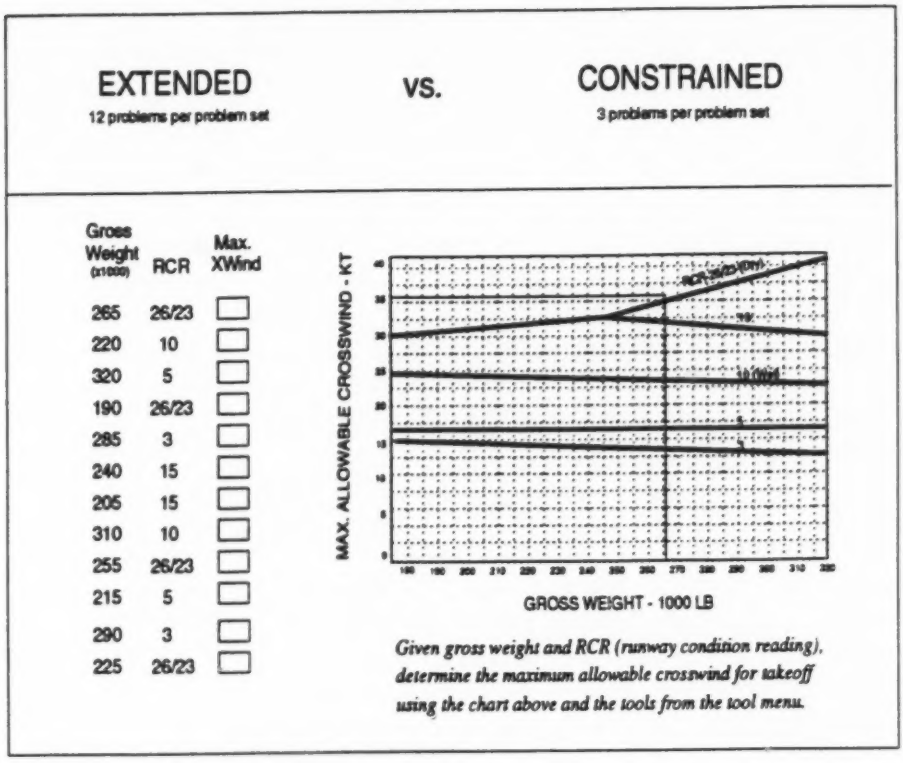

Figure 1
Examples of Problem Set for Determining Maximum Allowable Crosswind Given Gross Weight and RCR

The final group of problem sets (7, 8, and 9) required the learner to integrate all earlier problem sets. These problems involved determining the maximum allowable crosswind values, computing the wind component values, then deciding whether to proceed or abort the takeoff based on the computed information.

Learning Outcome Measures

We wanted to assess the acquisition of tutor-specific skills as well as general graph reading and interpreting skills that may have been enhanced as a function of learning from the tutor. To achieve this end, we created three categories of posttests: (a) Basic graph knowledge and skills, (b) Complex graph knowledge and skills, and (c) Tutor-specific knowledge and skills. Within each category, several tests measured declarative knowledge and procedural skill acquisition separately. All tests were administered on-line at the conclusion of the tutor.

1. *Basic graph knowledge and skills*. This test was divided into five parts and consisted of 50 items altogether. It was a multiple choice format (with 10 alternative responses to choose from). For example: The horizontal part of a graph is called the _____? (correct answer is x-axis).

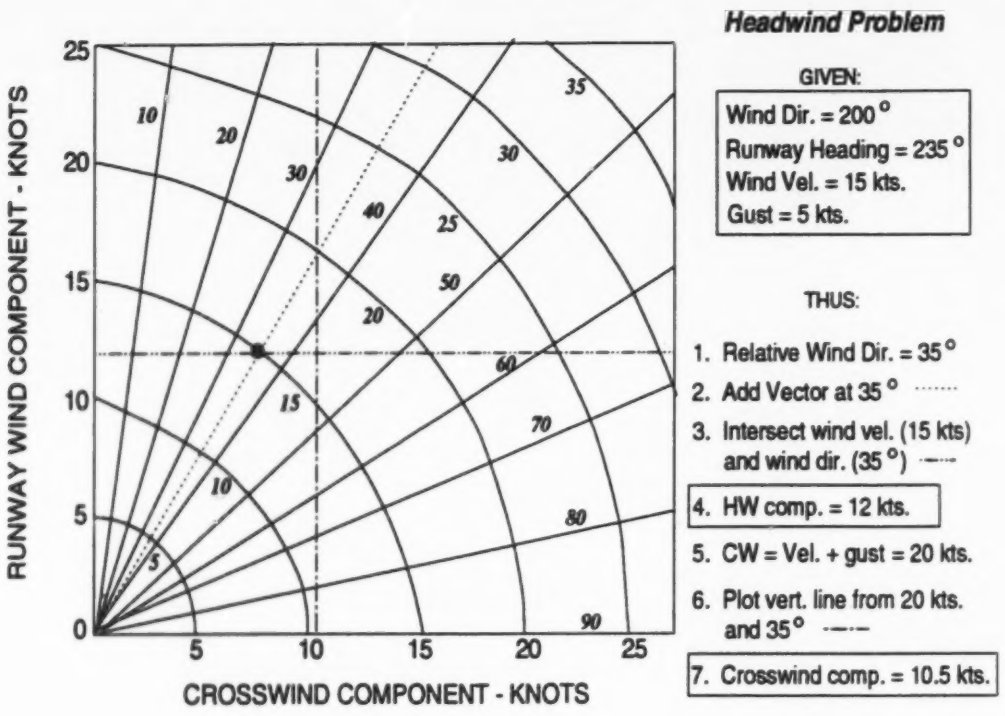

Figure 2
Seven-Step Solution for Solving Headwind and Crosswind Problems from the Wind Components Chart

2. *Complex graph knowledge and skills*. We created this test to assess performance on more complex graph-related problems. There were three main parts: Understanding functions, Story problems, and Complex graph interpretation. Posttest 2 items were designed to measure graph interpretation skills such as understanding functional relations and multidimensional graphs. The story problems were created to be analogous to some of the problems encountered in the flight engineering tutor, but without any of the vernacular. There were 30 items in this test, multiple choice format with six alternatives to choose from.

3. *Tutor-specific knowledge and skills*. We created the final posttest to assess the depth and breadth of knowledge and skills acquired from the tutor. All three parts comprising this posttest were tutor-specific. The three parts measured: Declarative knowledge, Procedural knowledge, and Graph interpretation. There were 45 items altogether in this posttest, administered in a multiple choice format with six alternatives to choose from.

Error Types

Ten different types of errors were tallied during the learning process. These were classified as either numerical or conceptual errors. *Numerical* errors included: (a) incorrect HW or TW value entered, (b) incorrect maximum allowable crosswind value, (c) incorrect crosswind component computed, (d) omitted data in TOLD sheet, and (e) failure to abort an unsafe flight (or choosing to abort a safe flight) due to incorrect wind component value(s). *Conceptual* errors were: (a) reversing axes on Wind Components chart, (b) reversing axes on Maximum Allowable Crosswind chart, (c) reversing vectors on Wind Components chart, (d) interpreting from incorrect curve on the Maximum Allowable Crosswind chart, and (e) using an incorrect vector on the Wind Components chart.

Procedure

Subjects were tested in groups of approximately 20 persons, and there were twenty groups tested, total.[1] Each group spent seven days (about six hours per day) in this study. Subjects began the study being tested on basic cognitive process measures (not relevant to this paper), and then were randomly assigned to one of the learning environments of the tutor. Directly following the completion of the tutor, subjects were administered the criterion posttest battery.

RESULTS

As expected, subjects in the constrained environment did complete the tutor faster than subjects in the extended environment (*Constrained* M = 8.0 hr, SD = 4.0, N = 181; *Extended* M = 10.6 hr, SD = 4.5, N = 183). An ANOVA on these data showed the difference to be significant ($F_{1,362} = 33.14$; $p < .001$).

But a more interesting question addressed how well the respective groups performed on the outcome measures. Table 1 shows each of the individual (and average) posttest scores separated by the two versions of the tutor. Even-odd reliabilities of the Posttests were high ($r = .91$, Posttest 1; $r = .91$, Posttest 2; $r = .90$, Posttest 3).

These results were very surprising. In all of the outcome measures, there were no differences between the two practice environments. In addition, this finding was not a function of differential incoming knowledge. A pretest was administered to all subjects before starting the tutor corresponding to the same item types as in Posttest 1 (i.e., Basic Graphs). There were no differences

[1]Some individuals dropped out before completing all parts of the study.

on any of the individual tests by treatment group, or in the overall pretest score (*Pretest-Constrained* M = 61.8, SD = 20.16, N = 181; *Pretest-Extended* M = 62.6, SD = 18.2, N = 183; $F_{1,362} = 0.19$, NS).[2]

Table 1. Posttest Scores Separated by Learning Environment

Test	Constrained (N=177)	Extended (N=179)	F	Signif
1 - BASIC GRAPHS				
Graph Knowledge	60.40	57.82	0.81	NS
Read Points	53.45	52.45	0.17	NS
Read Relations	69.77	66.15	2.01	NS
Interpret Points	62.49	63.80	0.34	NS
Interpret Relations	52.26	52.29	0.00	NS
(Average)	**59.67**	**58.48**	**0.32**	**NS**
2 - COMPLEX GRAPHS				
Functions	27.82	30.00	0.35	NS
Story Problems	56.47	59.32	1.99	NS
Complex Graphs	69.44	70.22	0.10	NS
(Average)	**56.45**	**58.37**	**0.84**	**NS**
3 - TUTOR SPECIFIC				
Declar. Knowledge	61.02	60.89	0.00	NS
Proced. Knowledge	48.08	48.21	0.00	NS
TOLD sheet	62.71	65.86	2.21	NS
(Average)	**59.12**	**60.83**	**0.65**	**NS**

The next set of questions concerned differences between groups as a function of latencies and errors per problem set. Figure 3 shows the data for the three groups of problems. Problem sets 1, 2, and 3 all involve figuring out maximum allowable crosswind; sets 4, 5, and 6 involve computing headwind, tailwind, and crosswind values; and finally, sets 7, 8, and 9 involve integrating the prior problem sets. The first row of graphs represents solution time by problem. The second row represents error data (total errors per problem).

[2] In addition, each posttest was regressed against the mean pretest score and the residuals saved. Comparing outcomes with these residualized posttest scores again showed no significant differences between conditions.

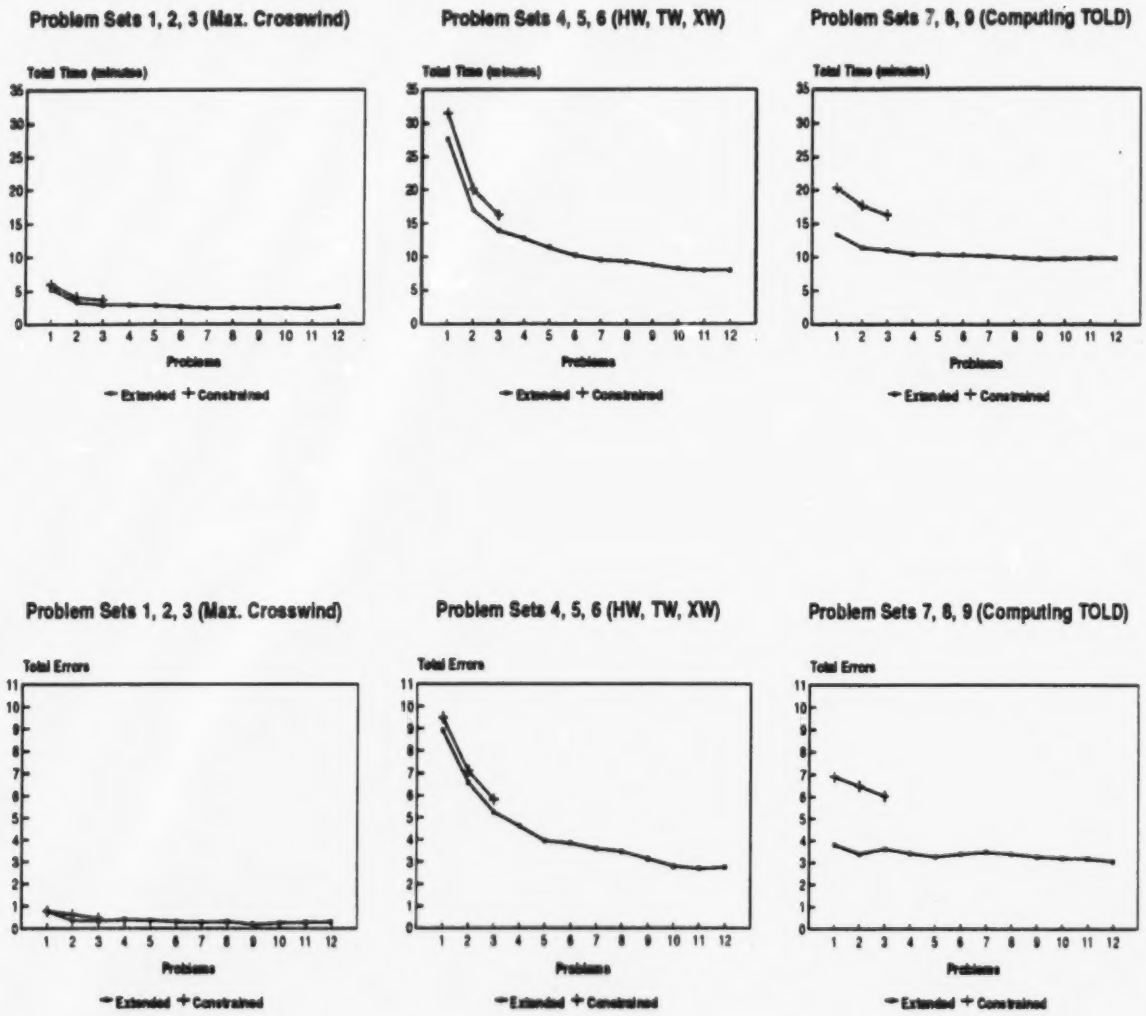

Figure 3
Latency and Error Data Across Problem Sets

For the easiest problem sets, there were no strong differences between the two groups for either latency or error data. But the second group of problem sets shows some separation between learning curves whereby subjects in the constrained version began to take longer per problem compared to those in the extended version. Finally, for the complex problems (sets 7, 8, and 9), the gap has widened considerably for the time data. Subjects appeared to have adjusted their learning times upward in the constrained version. The mean time to learn these problem sets for subjects in the constrained version was 54.24 minutes (SD = 22.13, N = 177), and the mean time for subjects in the extended version was 35.77 minutes (SD = 15.34, N = 178). This finding represented a significant difference between the learning environments ($F_{1,353} = 83.61$, $p < .001$).

In terms of the error data, only "total errors" were plotted. Again, the same pattern of differences between learning environments emerged. The number of errors made during the easiest problems (sets 1, 2, and 3) was about the same for the two learning environments. For the next grouping of problems (sets 4, 5, and 6), a slight separation between groups began to appear, but this difference was not significant. By the final group of problems (sets 7, 8, and 9), subjects in the constrained environment were making more errors than subjects in the extended environment. This difference was statistically significant ($F_{1,353} = 25.68$, $p < .001$).

To determine any differences in the types of errors committed, the error data were separated into either "numerical" or "conceptual" errors and we computed a proportion: numerical divided by conceptual errors. To test for differences between the two practice environments, we computed a one-way Analysis of Variance (ANOVA) on this proportion by environment. Results showed that subjects in the constrained environment had a higher proportion of numerical to conceptual errors ($M = 2.69$; $SD = 1.55$; $N = 181$) compared to subjects in the extended environment ($M = 2.12$; $SD = 0.88$; $N = 183$). This difference was significant ($F_{1,362} = 18.82$; $p < .001$).

DISCUSSION

Practice effects were investigated in relation to overall learning time, learning outcome, and parameters of skill acquisition (latencies and errors). The first hypothesis was supported: subjects in the constrained environment *did* require significantly less time to complete the tutor compared to subjects in the extended environment. The second hypothesis, that subjects in the extended environment would perform better on outcome measures than subjects in the constrained environment, was not supported and the surprise finding was that there were no differences on any of the outcome measures between the two groups. This finding may, in part, be explained by the third finding that subjects in the constrained environment gradually increased learning times per problem, presumably to compensate for having so few practice problems to solve (thus, hypothesis 3 was supported). Finally, it was hypothesized that subjects in the constrained environment would make more conceptual than numerical errors. The opposite was found. But this finding can actually account for the other unexpected finding about the comparability of outcome measures between groups. Because subjects in the constrained environment were investing more time per problem, especially within the most difficult problem sets, they were able to extract the conceptual issues from the problems, but it cost them additional time per problem. Thus, the errors they made were less conceptual and more numerical (i.e., a higher proportion of numerical/conceptual errors compared to the subjects in the extended environment). If they had made more conceptual errors (in relation to numerical errors), then we would expect to see differences in outcome performance.

In conclusion, less practice (1/4 the problems) can actually result in comparable learning outcomes to more extensive practice environments. The cost is in terms of more time invested per problem as well as less precise computations (i.e., numerical errors). But numerical errors can have severe consequences in the real world. Thus, these data suggest that the tutor should remediate numerical errors, which it currently does not. Additional research is indicated to determine the boundary conditions under which we can see these same results. In other words, just how low can we go? Furthermore, research is planned to test if differences in retention could be detected between the two groups after a significant period of time has elapsed (e.g., 9 months to 1 year). Findings may show that benefits from the extended condition show up in terms of better retention compared to subjects learning from the constrained environment.

REFERENCES

Ackerman, P.L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General*, *117*, 288-318.

Anderson, J.R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review*, *94*, 192-210.

Carlson, R.A., & Yaure, R.G. (1990). Practice schedules and the use of component skills in problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 484-496.

Fisk, A.D., & Rogers, W.A. (in press). The Application of Consistency Principles for the Assessment of Skill Development. In J.W. Regian & V.J. Shute (Eds.) *Cognitive Approaches to Automated Instruction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Gick, M.L., & Holyoak, K.J. (1987). The cognitive basis of knowledge transfer. In S.M. Cormier & J.D. Hagman (Eds.) *Transfer of Learning*. New York: Academic Press.

Lesgold, A., Bunzo, M.S., & Eastman, R. (1989). *Windy, the Flight Engineering Tutor*. Unpublished tutor. Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing I. Detection, search, and attention. *Psychological Review*, *84*, 1-66.

Woltz, D.J. (1988). An investigation of the role of working memory in procedural skill acquisition. *Journal of Experimental Psychology: General*, *117*, 319-331.